ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (A)

Dick Hirsch is assigned the task of analyzing the operation of a recently invented hydraulic accelerator for a machine gun. Through the use of elementary mechanics he formulated and solved the equation in about two days. The case is divided into three parts: the problem statement, Hirsch's solution, and a subsequent development.

ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (A)

Introduction

In March of 1952 Dick Hirsch joined Aircraft Armaments, Inc.* as a Senior Engineer in the Structures and Aerodynamics Department. Dick had a BS degree in Aeronautical Engineering and an MS in Applied Mathematics. He left a job as a Vibrations Engineer with Piasceki Helicopter Corporation† to join AAI. One of his first assignments was to a project concerned with developing a new machine gun for installation in Army tanks. He was to work with the designers in the Ordnance Department and be responsible for the performance and stress analysis of the new weapon. Dick's recollections about this period of time are as follows: "I was assigned to the project in March 1952 and conducted the analysis described in the case study at that time. I formulated and solved the equations in about two days. During the next two years I was intimately concerned with all the dynamic and structural aspects of the design but at the same time I was responsible for similar work on other projects.

"By 1956 I had advanced to the position of Chief Structures Engineer and had a Department of about 30 engineers responsible for mechanical analysis on all company projects. The machine gun project was active until March 1959 but my personal contributions were minimal after 1956."

Background

In March of 1952, AAI employed about 150 people and was about 2 years old. The company had been formed by a group of engineers from the Martin Company who were convinced that there was a need for a company that could design and produce weapons systems as opposed to designing airplanes and sticking the armament on as an afterthought. The initial efforts of the company were devoted to trying to sell new ideas to the Air Force. This met with little success and the Army and Navy were approached. The Army was concerned with protecting tanks and ground forces from attacks by new high speed aircraft then being developed. The standard .50 caliber Browning machine gun simply would not fire fast enough to have much chance of hitting low flying, high speed aircraft. The Army wanted a new weapon which would fire twice as fast (1000 rounds/minute) as the Browning, at aircraft, and could also fire the normal 500 RPM at ground targets. They could have used the aircraft version of the Browning which achieved a rate of 1000 RPM by reducing the weight of the recoiling barrel from 30 lbs to 9 lbs. The trouble with this solution was that the light barrel wore out very quickly and was not considered practical for ground force use. The problem which the AAI designers tackled was to design a new machine gun, using the standard heavy barr l, which could achieve a firing rate of 1000 RPM.

Irwin R. (Win) Barr, one of the company founders, was chief of the company's Ordnance Department. Win was intimately familiar with the Browning machine gun. He knew that it was a recoil-operated weapon. The reaction from the bullet being propelled through the barrel caused the barrel to acquire a rearward velocity. The kinetic energy of the recoiling parts was transferred to the bolt of the weapon through a cam called the accelerator. The function of the accelerator was to transfer energy to the recoiling bolt and increase its velocity. Since the bolt had to travel approximately seven inches aft in order to

*Now AAI Corporation of Cockeysville, Maryland.

†Now Vertol Division of Boeing

extract the empty cartridge case and operate the feed mechanism and feed a new round into the chamber, while the barrel traveled only an inch or so, the rate of fire of the weapons was controlled by the velocity of the bolt. Win reasoned that if the bolt could be made lighter and the accelerator made more efficient, the rate of fire could be increased. Once achieving the high rate of fire, the low rate could be achieved by dissipating energy and slowing the bolt down. He considered the key problem, then, was to design a new accelerator with as little weight as possible in its moving parts and increasing the effieiency by eliminating friction as much as possible.

After considering various mechanical means for transferring energy, Win hit upon the idea of using hydraulic fluid as a means for effecting the transfer. This idea seemed to meet requirements for low weight and low friction. He reasoned that a conventional hydraulic cylinder could multiply an input foree and transfer energy efficiently so why not use this concept in a dynamie application. The basic scheme is shown in Exhibit A-1. The unit consists of a circular cylinder containing 3 pistons, a spring and hydraulic fluid. The pistons are referred to as the barrel piston, the bolt piston and the spring piston. The operation of the unit can be described as follows: All motion takes place relative to a fixed part of the gun called the receiver. At the instant the projectile is fired, the bolt and barrel are mechanically locked together in their most forward (muzzleward) position. Due to the gas pressure in the barrel, the barrel and bolt start to recoil (travel aft). A fixed amount of rearward travel is allowed in order for the gas pressure to drop sufficiently to allow the bolt to unlock and extract the empty shell case. At the instant that the bolt is unlocked (by cam surfaees) from the barrel, the barrel strikes the barrel piston. The motion of the barrel piston moving into the hydraulic fluid causes a pressure to build up whieh is regulated by the spring. This pressure acting on the bolt piston causes it to accelerate the bolt increasing its velocity above its original recoil veloeity.

Win's hydraulic accelerator concept was described in a technical report and submitted to the Army. In July of 1951 a presentation was made at the Springfield Armory and as a result, in August of 1951, AAI submitted a proposal to modify a standard ealiber .50 Browning M.G. to incorporate the hydraulic accelerator. A contract was awarded and work initiated in November 1951. In March of 1952 the contraet was amended to include the design, fabrication and testing of a prototype of a new machine gun incorporating the hydraulie accelerator principle. This new weapon was to be designated the T-175 machine gun. The total value of the original contract plus amendments was $152,000.

Preliminary Analysis of the Hydraulic Accelerator

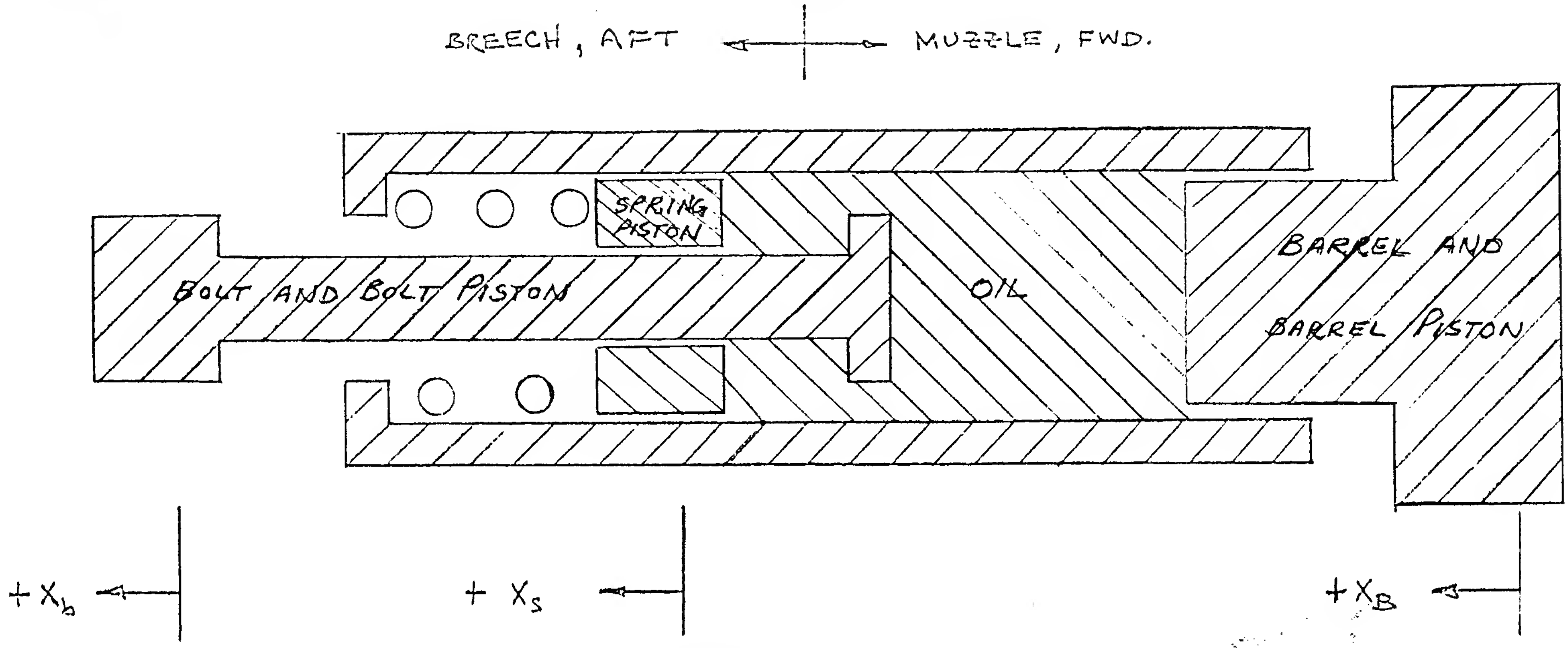
At the time that Dick Hirsch joined the project team, the outside dimensions of the accelerator had been set, based upon space and geometrical eonsiderations. The design team was now concerned with how to apportion the available space among the various pistons. Win Barr had reasoned that since the bolt had to travel further than the barrel, its piston ought to be smaller (in area) than the barrel piston. Dick agreed with this and then, based upon basic considerations of momentum and energy, was able to show that a relationship such as sketched in Exhibit A-2 ought to exist. Dick then set out to derive an analytical expression relating the velocities, areas and weights of the various parts.

Exhibit A-3 is a photograph of the first prototype and shows the position of the hydraulic accelerator assembly relative to the barrel and reeeiver. Exhibits A-4 and

A-5 show two views of a test stand which was designed and built later in the program. Its purpose was to evaluate the performance of the hydraulic accelerator independent of any particular weapon. A falling weight, in the form of a pendulum, was used to simulate the recoiling barrel. The tests were conducted during the latter part of 1953 and demonstrated the validity of Dick's dynamic analysis.

Assignments:

1. Reconstruct Dick's reasoning leading to the graph shown in Exhibit A-2.
2. Assuming Exhibit A-2 is essentially correct, a given bolt velocity can be achieved with two different area ratios. What is the significance of the two different ratios?
3. Make a list of assumptions you would consider reasonable in carrying out a dynamic analysis of the accelerator.
4. Based upon your assumptions sketch the free body diagrams for each of the three pistons.
5. Derive the equation expressing the relationship shown in Exhibit A-2.



SYMBOLS

m_B	MASS OF BARREL AND BARREL PISTON
m_b	MASS OF BOLT AND BOLT PISTON
m_s	MASS OF SPRING AND SPRING PISTON (CONSIDERED NEGLIGIBLE)
A_B	NET AREA OF BARREL PISTON
A_b	NET AREA OF BOLT PISTON
A_s	NET AREA OF SPRING PISTON
X_B	DISPLACEMENT OF BARREL PISTON
X_b	DISPLACEMENT OF BOLT PISTON
X_s	DISPLACEMENT OF SPRING PISTON

k = SPRING CONSTANT

EXHIBIT A-1

SCHEMATIC OF HYDRAULIC ACCELERATOR

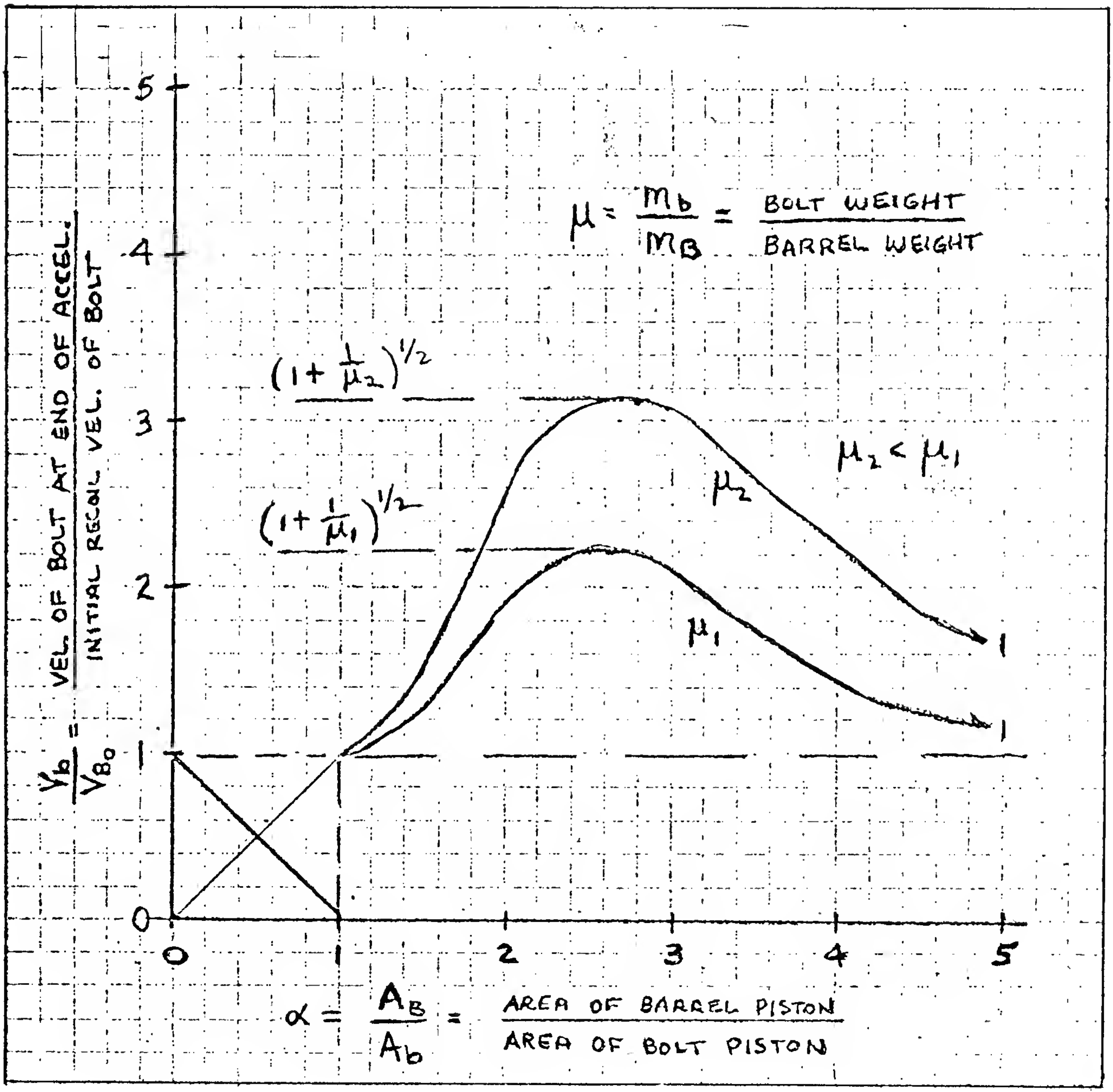


EXHIBIT A-2

EXPECTED RELATIONSHIP BETWEEN
BOLT VELOCITY AND PISTON AREAS

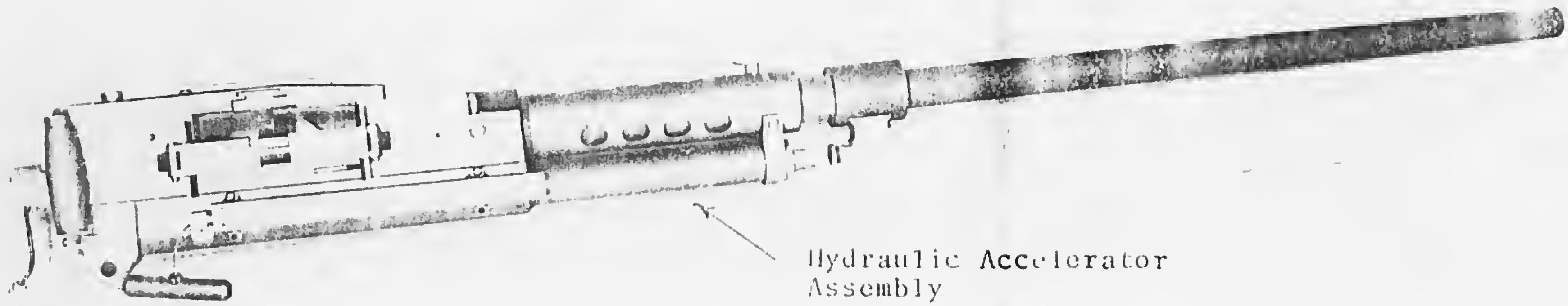


EXHIBIT A-3

FIRST EXPERIMENTAL MODEL OF THE T175 MG

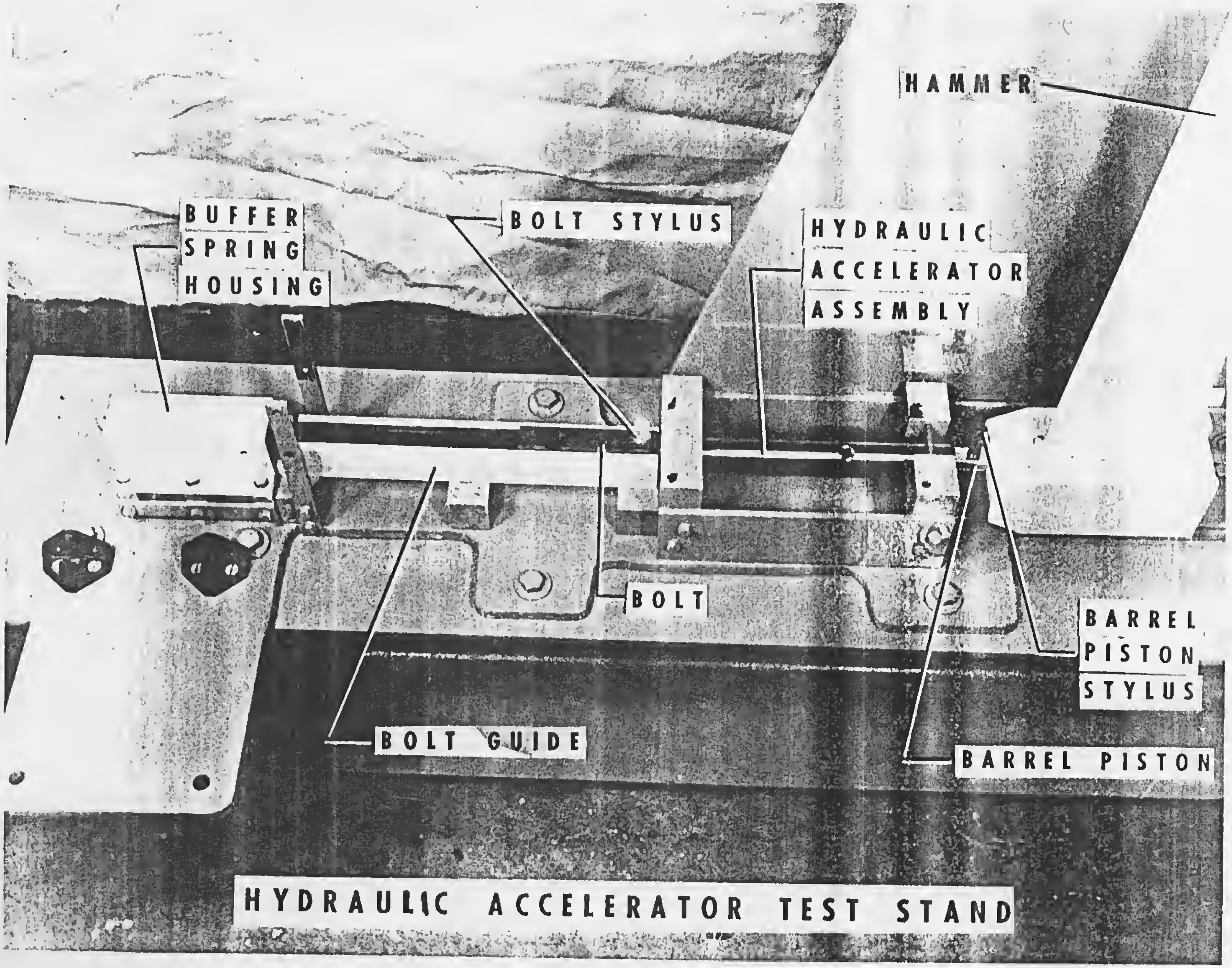

HAMMER
BUFFER SPRING HOUSING
BOLT STYLUS
HYDRAULIC ACCELERATOR ASSEMBLY
BOLT
BARREL PISTON STYLUS
BOLT GUIDE
BARREL PISTON
HYDRAULIC ACCELERATOR TEST STAND

EXHIBIT A-4

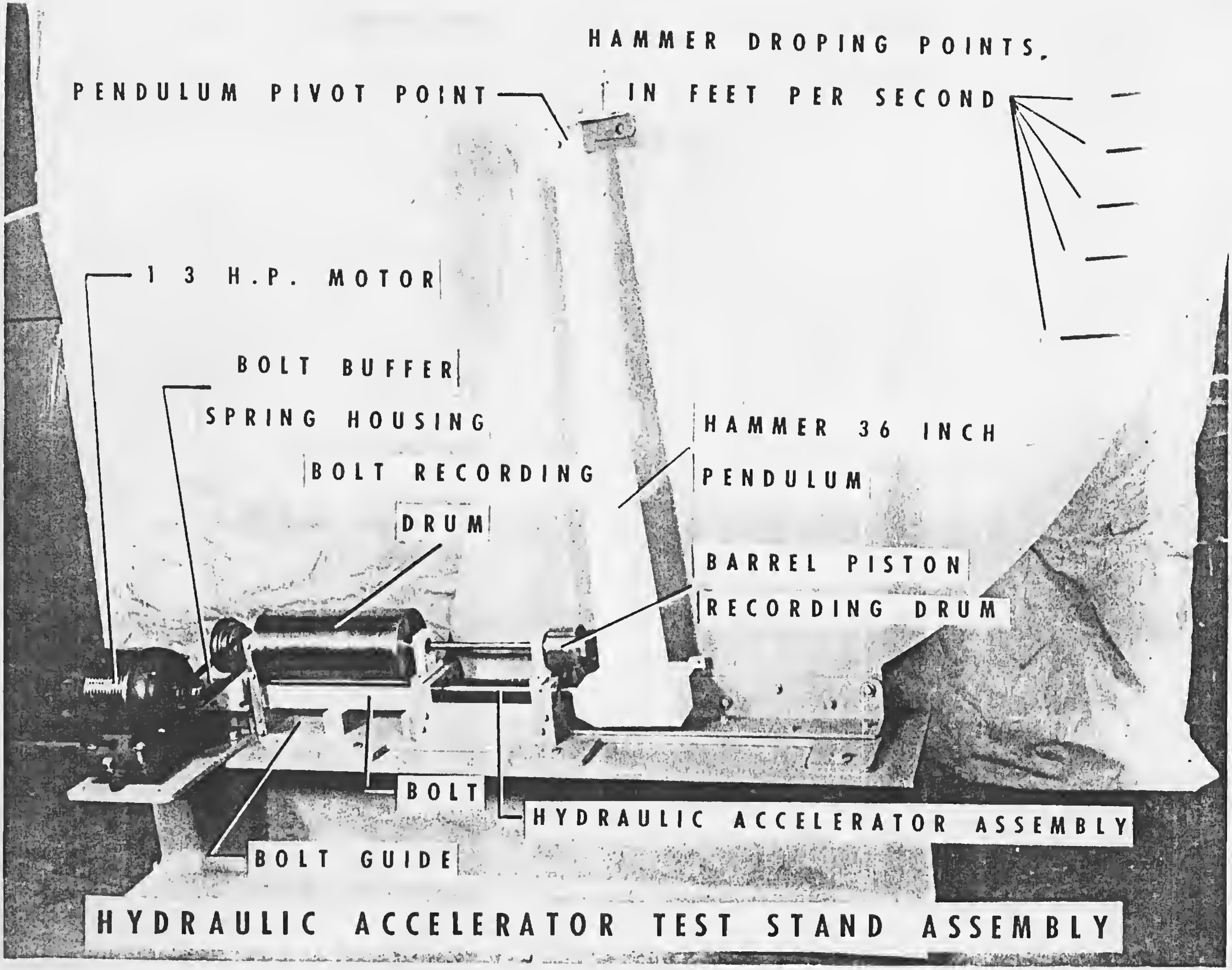

HAMMER DROPING POINTS.
IN FEET PER SECOND
PENDULUM PIVOT POINT
1 3 H.P. MOTOR
BOLT BUFFER
SPRING HOUSING
BOLT RECORDING
DRUM
HAMMER 36 INCH
PENDULUM
BARREL PISTON
RECORDING DRUM
BOLT
HYDRAULIC ACCELERATOR ASSEMBLY
BOLT GUIDE
HYDRAULIC ACCELERATOR TEST STAND ASSEMBLY

EXHIBIT A-5

ENGINEERING CASE LIBRARY

ECL 463B

ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (B)

 Written by Richard A. Hirsch. Published with support from the National Science Foundation.

ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (B)

Preliminary Analysis of the Hydraulic Accelerator

As a start, it was evident to Dick that at the instant when the barrel contacted the barrel piston the total kinetic energy available was

$$T = \tfrac{1}{2}(m_B + m_b) V_{B_o}^2$$

He reasoned that *if all* of this energy could be transferred to the bolt, then the kinetic energy at the end of acceleration would be

$$T = \tfrac{1}{2} m_b V_b^2$$

Equating these two energies, assuming no energy is stored or lost, the resulting bolt velocity would be

$$\frac{V_b}{V_{B_o}} = \left(\frac{M_B + M_b}{M_b}\right)^{1/2} = \left(1 + \frac{1}{\mu}\right)^{1/2}$$

This, then, represents the maximum velocity which can be achieved. For example, if the barrel weighs 30 lbs. and the bolt 2 lbs., the bolt velocity will be increased by a factor of four. Unfortunately, if a unique set of piston areas is required to achieve this condition, it cannot be determined from energy considerations alone.

Next, Dick considered the case where the areas of the bolt and barrel pistons were equal ($\alpha = A_B/A_b = 1$). If this were true, then the force acting on the bolt and barrel would be equal and opposite and act for the same length of time. Under these conditions the total momentum of the bolt and barrel would be conserved. If we retain the assumption of no energy storage or loss, then the following two equations apply:

$$(m_B + m_b) V_{B_o} = m_B V_B + m_b V_b$$

$$\tfrac{1}{2}(m_B + m_b) V_{B_o}^2 = \tfrac{1}{2} m_B V_B^2 + \tfrac{1}{2} m_b V_b^2$$

The only possible solution to this set of equations is

$$V_b = V_B = V_{B_o} \quad \text{or} \quad V_b/V_{B_o} = 1$$

and hence no energy is transferred when $\alpha = A_B/A_b = 1$.

Since $A_b < A_B$ (see Part A) Dick decided to consider next the case where the bolt piston area became very small ($A_B/A_b \to \infty$). In this case the force acting on the bolt would become very small and hence the bolt velocity would not change ($V_b/V_{B_o} \to 1$).

Summarizing the foregoing results Dick sketched the curves shown in Exhibit A-2. He thus established that there was, in fact, an optimum value for the piston area ratio. In examining his curves, Dick recognized that, in general, a particular bolt velocity could evidently be achieved with two different area ratios. He realized that this must be true because, when all of the available kinetic energy is not transferred, the barrel still retains some velocity but it could either be moving aft or forward. He recognized that since, eventually, the barrel must be made to return to its original position, it may be desirable to design the accelerator so that part of the available energy is used to stop the rearward barrel motion and give it a forward velocity.

Dick decided that the next step should be a

complete dynamic analysis of the accelerator.

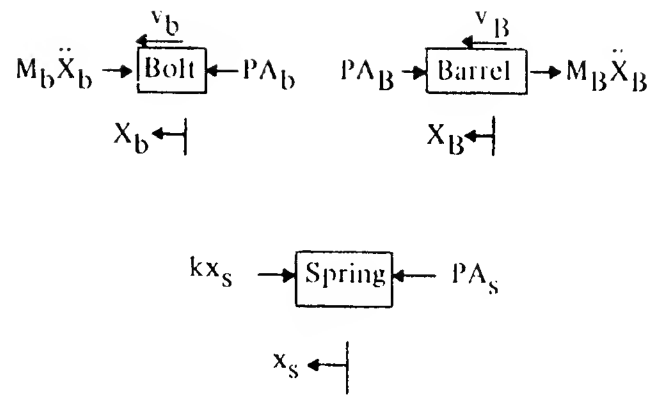
Assumptions for the Dynamic Analysis

Dick thought that his first analysis ought to be as simple as possible and yet lead to the results predicted in Exhibit A-2. He retained the assumption initially made that no energy was lost. He considered that the only energy storage element he would consider at this time was the spring within the accelerator itself. The other springs, such as the one holding the barrel in the firing position, could be considered later. He decided to neglect the mass of the spring and the spring piston. These were small compared to the mass of the barrel and the bolt and they could be included later.

Dick thought about the oil in the accelerator and since the total volume was small, he decided to neglect the compressibility of the oil compared with that of the spring. He recognized that a finite time would be required for the pressure pulse to be transmitted through the oil from the barrel piston to the bolt piston. He estimated that this time increment would be very small and decided to consider that the pressure pulse was transmitted instantaneously.

One further consideration came to mind. The two pistons were not attached to the parts they pushed and hence there would be impacts involved. Dick decided that for this first analysis, at least, he would assume that once contact between the piston and the part was made, it was maintained.

Utilizing all these assumptions, Dick drew the following free body diagrams:



Equations of Motion

From the free body diagrams, the following equations were obtained:

$$M_B\ddot{X}_B - PA_B = 0 \tag{1}$$

$$M_b\ddot{X}_b + PA_b = 0 \tag{2}$$

$$kX_s + PA_s = 0 \tag{3}$$

These three equations contain four unknowns: X_B, X_b, X_s, P and we evidently require another equation. Dick examined his list of assumptions and recognized that he had not expressed the fact that he had assumed the oil was incompressible. If the oil is incompressible then the volume displaced by the barrel piston moving into the oil must be equal to the volume displaced by the bolt and spring pistons moving out

of the oil. In symbols then,

$$A_B X_B = A_b X_b + A_s X_s \qquad (4)$$

and we have the required fourth equation.

Solution of the Equations

Dick decided to reduce the set of 4 equations to a single equation. He was able to do this as follows:

1. differentiate 4) twice

$$A_B \dot{X}_B = A_b \dot{X}_b + A_s \dot{X}_s \qquad (5)$$

$$A_B \ddot{X}_B = A_b \ddot{X}_b + A_s \ddot{X}_s \qquad (6)$$

2. rearrange 1) and 2)

$$\ddot{X}_B = -\frac{PA_b}{M_B}$$

$$\ddot{X}_b = \frac{PA_b}{M_b}$$

3. substitute in 6)

$$-\frac{PA_B^2}{M_B} = \frac{PA_b^2}{M_b} + A_s \ddot{X}_s$$

or

$$\ddot{X}_s + \frac{P}{A_s}\left(\frac{A_b^2}{M_b} + \frac{A_b^2}{M_B}\right) = 0$$

4. now use 3) in the form

$$P = \frac{kx_s}{A_s} \qquad (7)$$

o that finally

$$\ddot{X}_s + \frac{k}{A_s^2}\left(\frac{A_b^2}{M_b} + \frac{A_B^2}{M_B}\right) X_s = 0$$

And if we let

$$\omega^2 = \frac{k}{A_s^2}\left(\frac{A_b^2}{M_b} + \frac{A_B^2}{M_B}\right) \qquad (8)$$

the governing equation is

$$\ddot{X}_s + \omega^2 X_s = 0 \qquad (9)$$

and its solution is

$$X_s = C_1 \sin \omega t + C_2 \cos \omega t$$

The constants C_1 and C_2 are to be evaluated from the initial conditions. We know at time zero

$$t = 0 \quad X_b = X_B = 0\ ;\ \dot{X}_b = \dot{X}_B = V_{B_o}$$

and hence from equations 4) and 5)

$$X_s = 0$$

$$\dot{X}_s = \frac{A_B - A_b}{A_s} V_{B_o}$$

The assumptions of instantaneous pressure transmittal and oil incompressibility require that the spring piston has a finite velocity at time zero.

Evaluating the arbitrary constants we find

$$C_2 = 0$$

$$C_1 = \frac{A_B - A_b}{A_s} \frac{V_{B_o}}{\omega}$$

and so

$$X_s = \frac{A_B - A_b}{A_s} \frac{V_{B_o}}{\omega} \sin \omega t$$

and from 7)

$$P = (A_B - A_b) \frac{kV_{B_o}}{A_s^2 \omega} \sin \omega t$$

we can now substitute in 1) and 2) and integrate and evaluate the constants of integration and hence obtain

$$X_B \quad V_{B_o} t - \frac{A_B}{M_B} (A_B - A_b) \frac{kV_{B_o}}{A_s^2 \omega^3} (\omega t - \sin \omega t)$$

$$X_b = V_{B_o} t + \frac{A_b}{M_b} (A_B - A_b) \frac{kV_{B_o}}{A_s^2 \omega^3} (\omega t - \sin \omega t)$$

The Bolt Velocity Formula

We wish to compare the bolt velocity at the end of acceleration to its initial velocity. Acceleration ends when P=0 which occurs when $\omega t = \pi$. Now

$$\dot{X}_b = V_{B_o} + \frac{A_b}{M_b} (A_B - A_b) \frac{kV_{B_o}}{A_s^2 \omega^2} (1 - \cos \omega t)$$

When $\omega t = \pi$ let $\dot{X}_b = V_b$

$$V_b = V_{B_o} [1 + \frac{2A_b(A_B - A_b)k}{M_b A_s^2 \omega^2}]$$

and using 8) and letting $\mu = M_b/M_B$, $\alpha = \frac{A_B}{A_b}$

we get

$$\frac{V_b}{V_{B_o}} = 1 + \frac{2(\alpha - 1)}{1 + \mu\alpha^2}$$

In a similar manner we can derive a formula for the barrel velocity at the end of acceleration

$$\frac{V_B}{V_{B_o}} = 1 - \frac{2\mu\alpha(\alpha - 1)}{1 + \mu\alpha^2} \qquad (11)$$

The maximum pressure is of interest and it occurs when $\omega t = \pi/2$.

$$\frac{A_s P_{Max}}{V_{B_o}\sqrt{kM_b}} = \frac{\alpha - 1}{\sqrt{1 + \mu\alpha^2}} \qquad (12)$$

These last three equations are plotted and shown in Exhibit B-1 for the case $\mu = 1/8$.

Equation 10) for the bolt velocity behaves as predicted in the preliminary analysis. When $\alpha = 1$, $V_b/V_{B_o} = 1$; when $\alpha \to \infty$, $V_b/V_{B_o} \to 1$. Differentiating

$$\frac{d}{dX}\left(\frac{V_b}{V_{B_o}}\right) = 2 \frac{(1 + \mu\alpha^2)(1) - (\alpha - 1)(2\mu\alpha)}{(1 + \mu\alpha^2)^2}$$

then if

$$\frac{d}{d\alpha}\left(\frac{V_b}{V_{B_o}}\right) = 0$$

$$\mu\alpha^2 - 2\mu\alpha - 1 = 0$$

and

$$\alpha_\mu = 1 + \sqrt{1 + \frac{1}{\mu}} \qquad (13)$$

$$\left.\frac{V_b}{V_{B_o}}\right)_M = (1 + \frac{1}{\mu})^{1/2} \qquad (14)$$

We now have determined the area ratio required to obtain the maximum energy transfer.

We can now see that if we desire to have the barrel moving back towards its original position when acceleration ends, we should choose an area ratio larger than the optimum.

Suggested Assignments

1. Modify the equations of motion to account for the following:

   a) mass of the spring piston

   b) compressibility of the oil

   c) viscous friction losses due to the motions of the three pistons

   d) the effects of a spring acting on the bolt and another spring acting on the barrel.

2. the hydraulic accelerator machine gun, as described herein, was designed and built. It performed essentially as predicted herein. When the gun was subjected to environmental tests such as high and low temperature, sand and dust, and humidity a fatal problem developed. Can you speculate as to what the problem was?

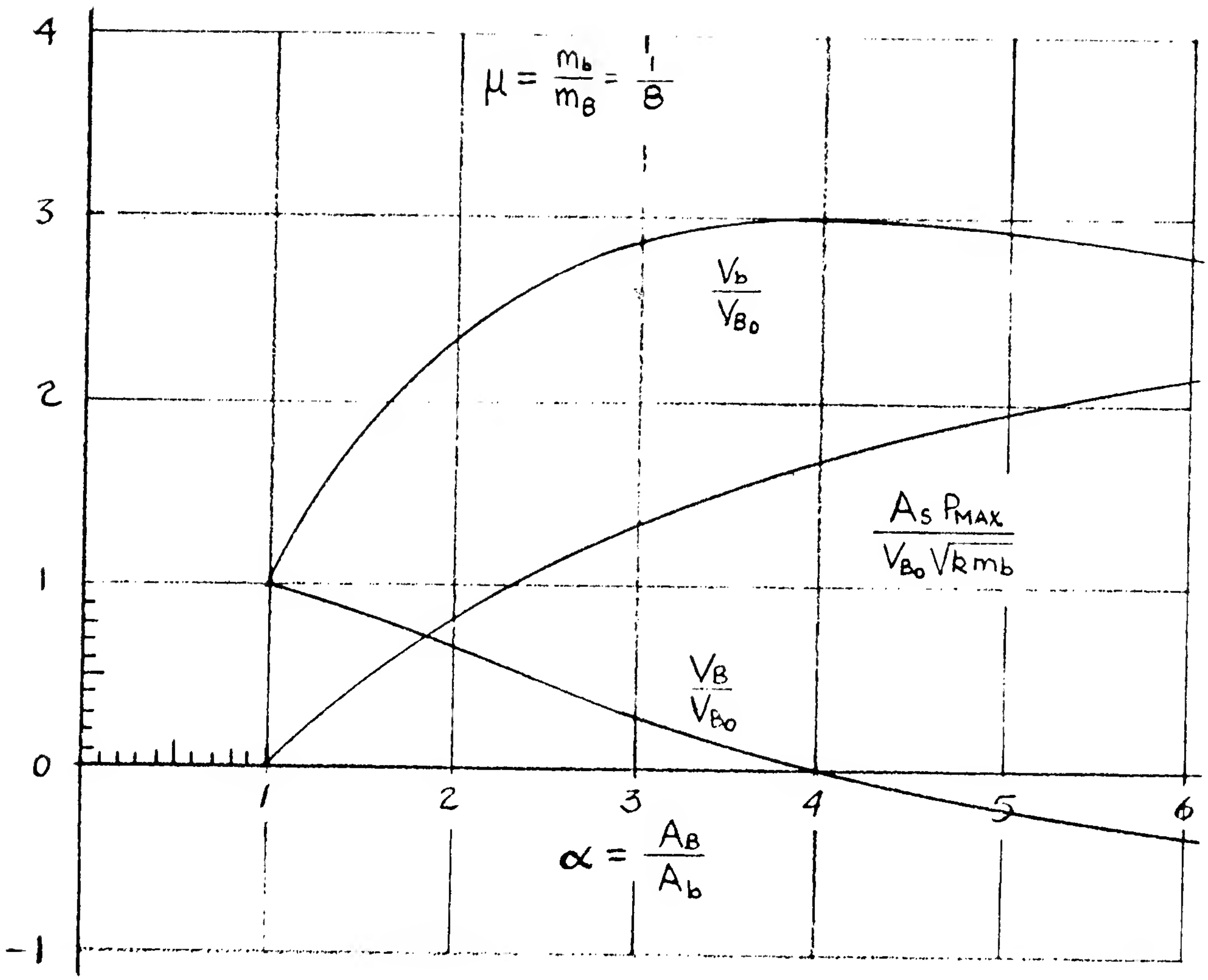


EXHIBIT B-1

HYDRAULIC ACCELERATOR PERFORMANCE CURVES

ENGINEERING CASE LIBRARY

ECL 163C

ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (C)

ANALYSIS OF THE HYDRAULIC ACCELERATOR MACHINE GUN (C)

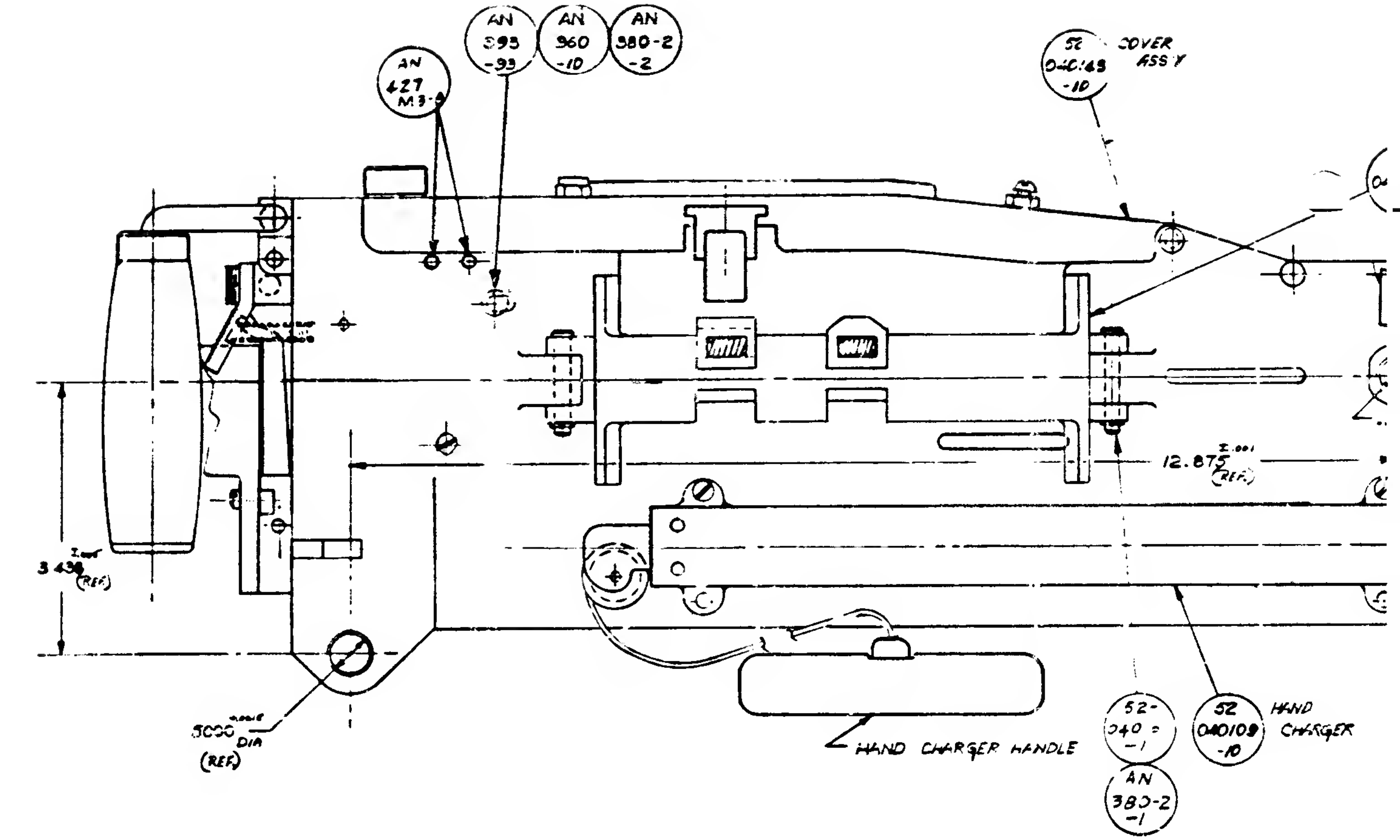
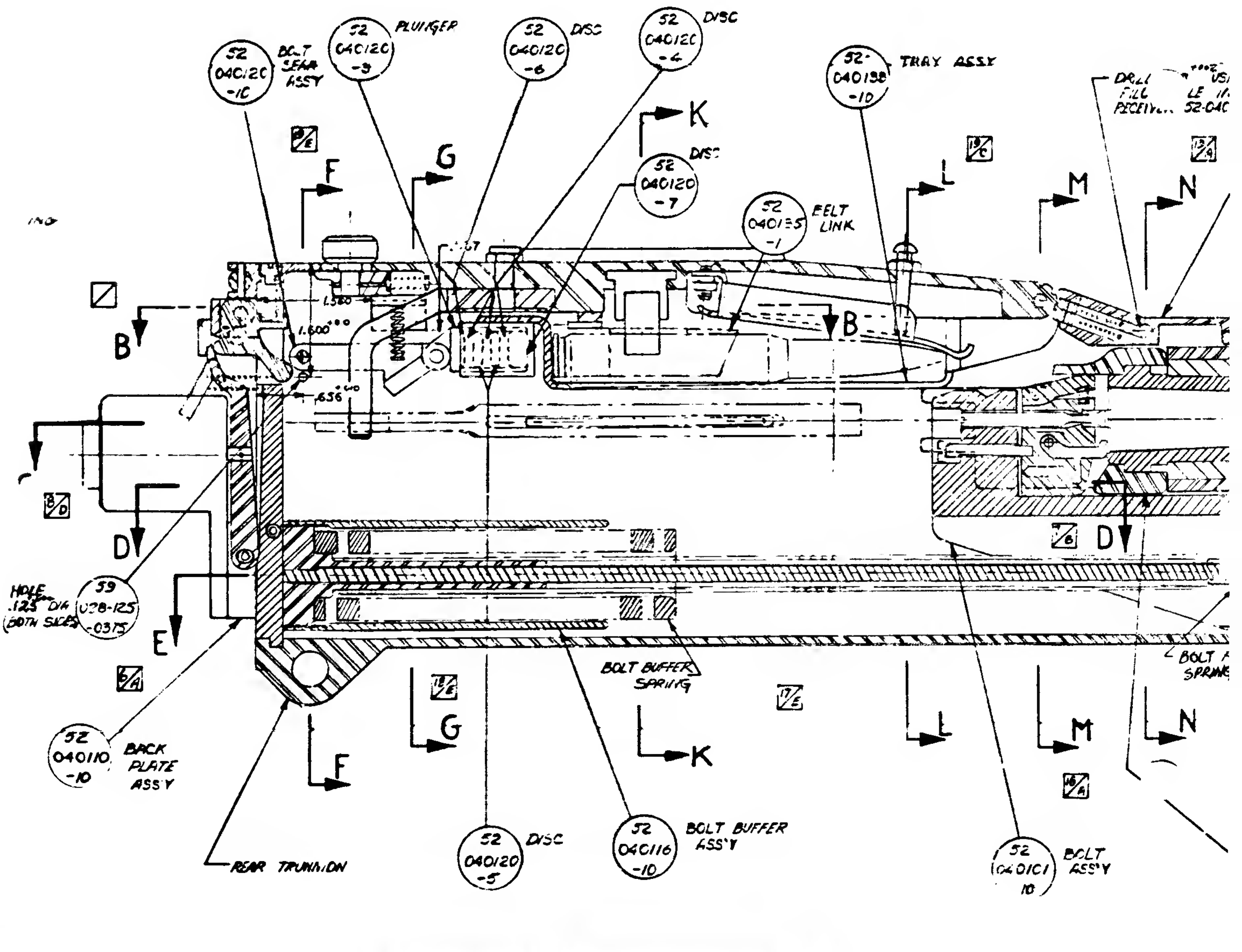
Epilogue

Tests of the hydraulic accelerator assembly were conducted during the fall of 1953 using the test stand shown in Exhibits A-4 and A-5. These tests verified the performance of the unit and the bolt velocities obtained were 80% of those predicted by Dick's analysis which had assumed no energy losses. In January of 1954 functional testing of the T-175 first prototype were initiated using the same test stand. The first firing tests were conducted in June 1954 and the contract was completed in January 1955. During this period a second contract, valued at $486,000, was awarded to AAI. This contract was for two preproduction prototypes.

During this second contract the Army conducted extensive environmental tests of the weapon. A continual problem was the loss of hydraulic fluid due to leakage. Various schemes were proposed to overcome this difficulty, but by this time, all parties agreed, that because of all the other design improvements, the gun would work as well or better with a mechanical accelerator. The mechanical accelerator was designed and incorporated and this version of the weapon was designated the T-175E1. The original version is shown in Exhibit C-1 and the E1 version is shown in Exhibit C-2.

As can be seen, the two versions are the same except for the accelerator. The T-175E1 was accepted by the Army and approved for production as the M85 machine gun. The gun is presently (1970) still in production at the Springfield Arsenal, Springfield, Massachusetts. The production facility is operated for the Army by General Electric.

In late 1959 the Army gave approval for the filing of a patent application. The patent was awarded to Win Barr in October 1962. Excerpts from the patent are included as Exhibit C-3. Eleven years elapsed between the time of the first presentation of the hydraulic accelerator concept to the Army and the award of the patent. The highlights of this eleven year history are summarized in Exhibit C-4.


AN 427 M3-4
AN 395 -93
AN 960 -10
AN 380-2 -2
52 040143 -10 COVER ASS'Y
12.875 (REF)
3.438 (REF)
.5000 DIA (REF)
HAND CHARGER HANDLE
52 040109 -10 HAND CHARGER
AN 380-2 -1

52 040120 -10 BOLT SEAR ASSY
52 040120 -3 PLUNGER
52 040120 -6 DISC
52 040120 -4 DISC
52 040120 -7 DISC
52 040135 -1 FELT LINK
52 040138 -10 TRAY ASSY
1.560
1.600
.656
HOLE .125 DIA (BOTH SIDES)
39 028-125 -0375
BOLT BUFFER SPRING
52 040110 -10 BACK PLATE ASS'Y
REAR TRUNNION
52 040120 -5 DISC
52 040116 -10 BOLT BUFFER ASS'Y
52 040101 10 BOLT ASS'Y

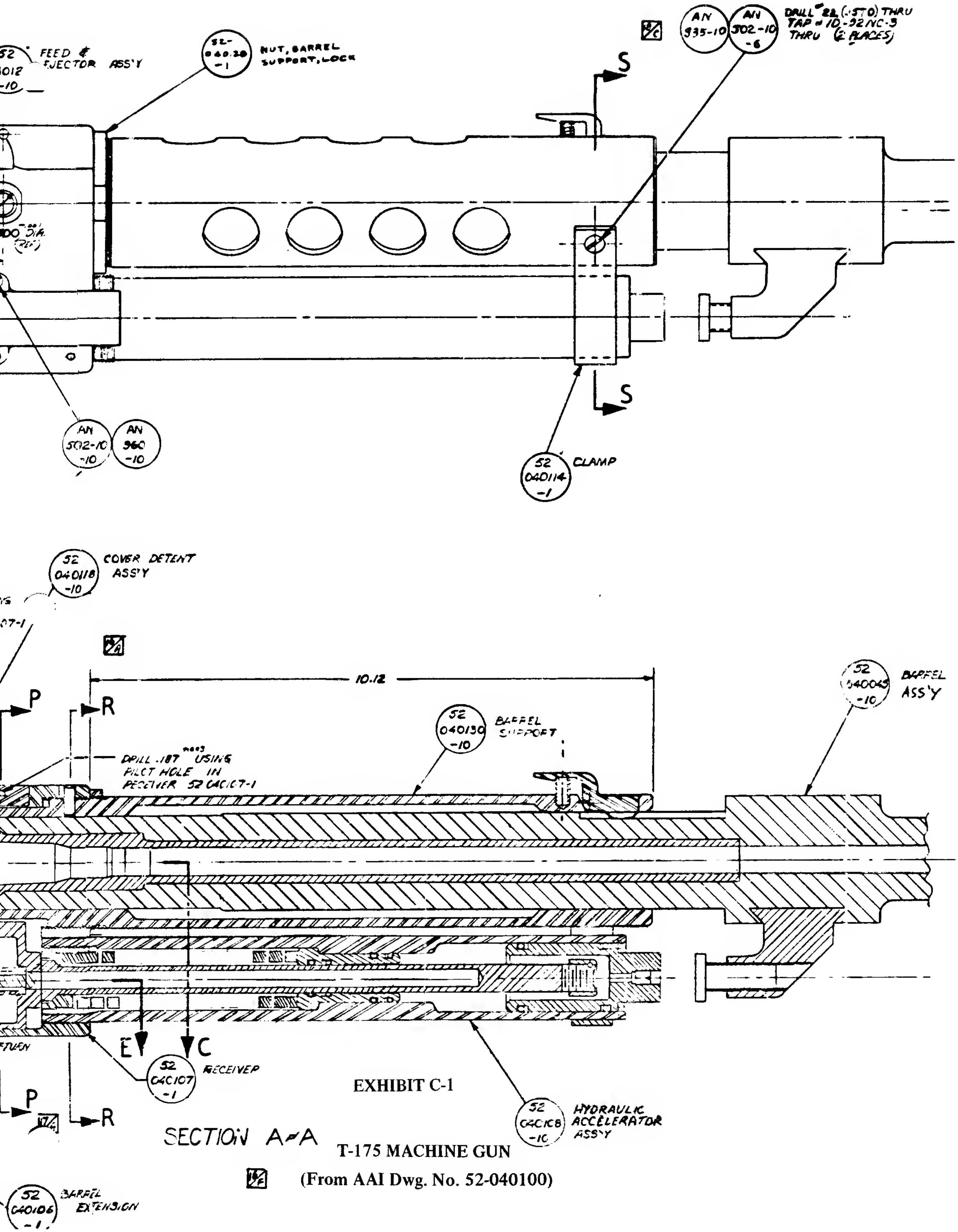


EXHIBIT C-1

T-175 MACHINE GUN

(From AAI Dwg. No. 52-040100)

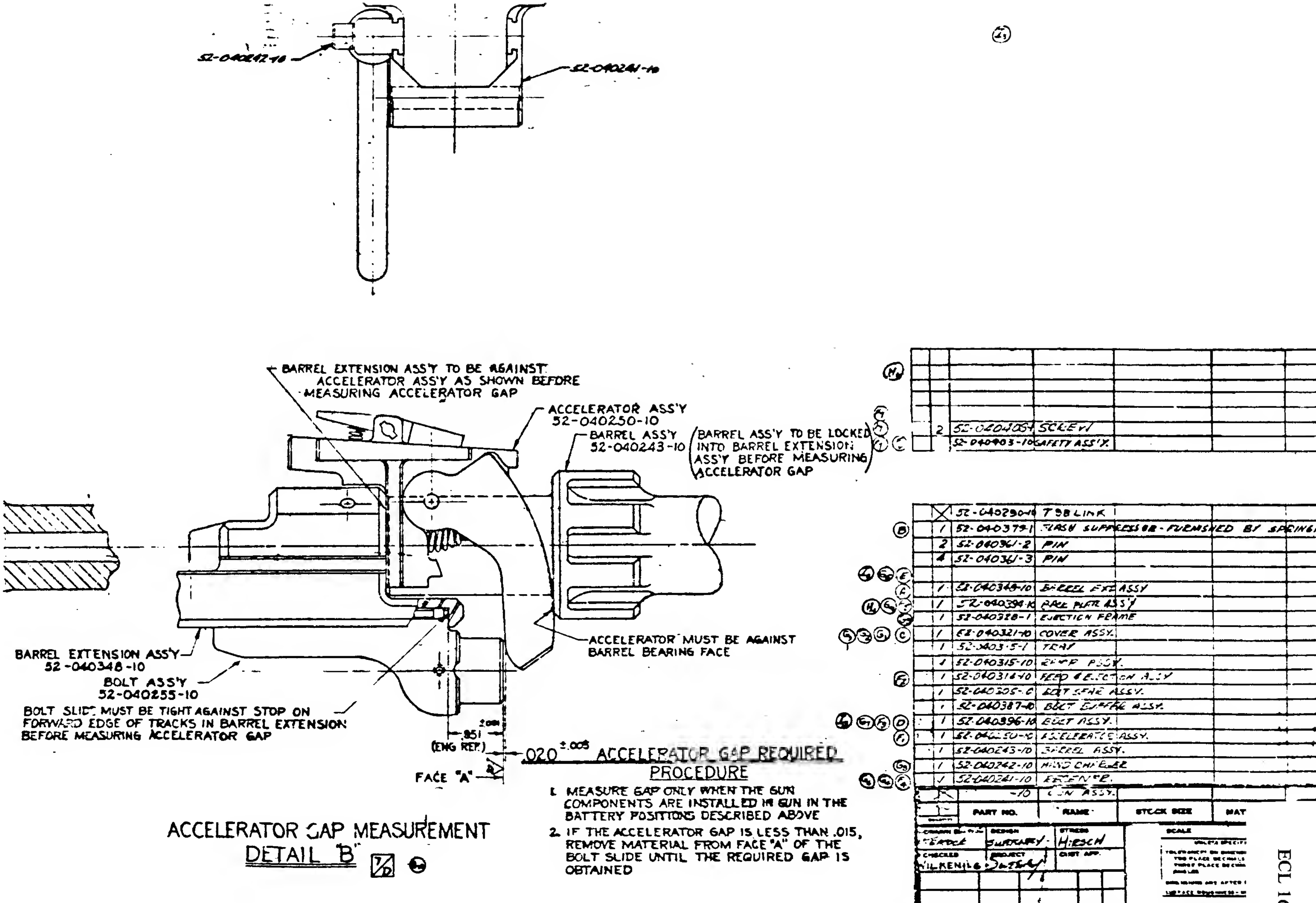


EXHIBIT C-2 T-175 E1 MACHINE GUN MECHANICAL ACCELERATOR
(From AAI Dwg. No. 52-040265)

Oct. 16, 1962 I. R. BARR 3,058,398
AUTOMATIC MACHINE GUN WITH RECOILING BARREL AND HYDRAULIC ACCELERATOR
Filed Dec. 23, 1959 2 Sheets-Sheet 1

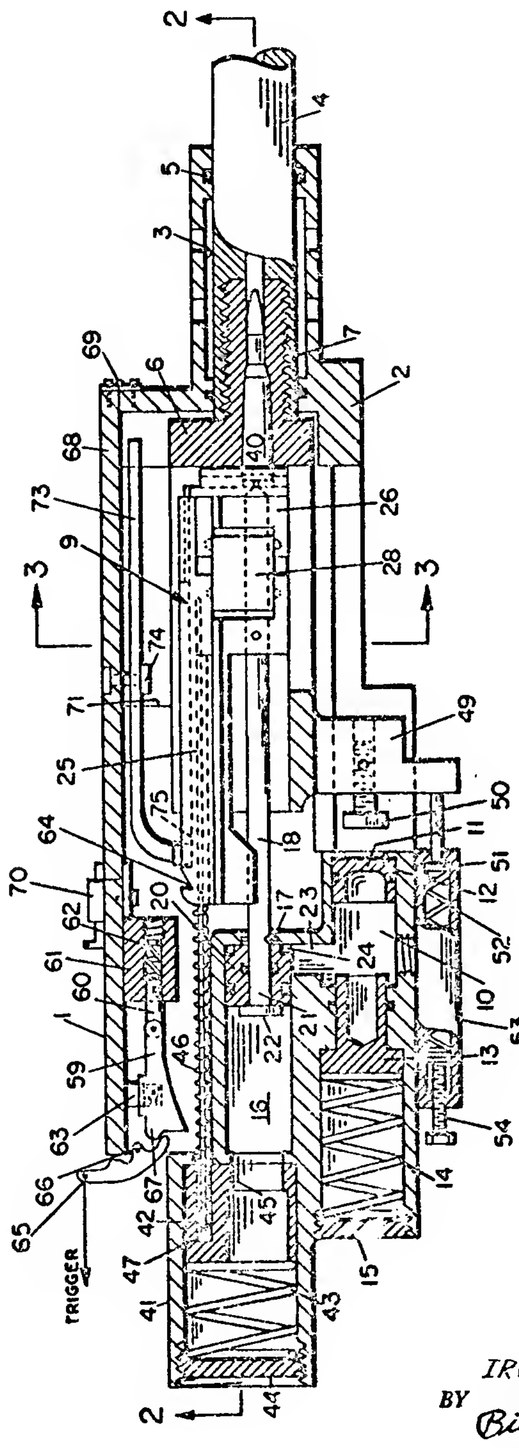


FIG. 1

INVENTOR.
IRWIN R. BARR
BY Billy G. Corber

EXHIBIT C-3

Figure 1 from Patent 3,058,398

United States Patent Office

3,058,398

Patented Oct. 16, 1962

1

2

3,058,398

AUTOMATIC MACHINE GUN WITH RECOILING BARREL AND HYDRAULIC ACCELERATOR

Irwin R. Barr, Baltimore County, Md., assignor to Aircraft Armaments, Inc., Baltimore, Md., a corporation of Ohio

Substituted for abandoned application Ser. No. 354,975, May 14, 1953. This application Dec. 23, 1959, Ser. No. 861,714

8 Claims. (Cl. 89—169)

This invention relates in general to firearms and more particularly to an automatic machine gun having a variable rate of fire.

An object of this invention is to provide an automatic machine gun having a hydraulic accelerator for actuating the breechblock and allowing the firing rate of the gun to be controllably varied over a wide range.

Another object of this invention is to provide a machine gun of simple and rugged construction and which is dependable in operation.

Still another object of this invention is to provide a machine gun which is smoother in operation than machine guns of conventional construction.

Further and other objects will become apparent from a reading of the following detailed description taken in conjunction with the accompanying drawing wherein like numbers refer to like parts.

In the drawing:

FIGURE 1 is a fragmentary sectional side view of the machine gun of this invention.

FIGURE 2 is a section taken on line 2—2 of FIGURE 1.

FIGURE 3 is a section taken on line 3—3 of FIGURE 1.

The machine gun as shown in FIGURE 1 includes a housing 2 having a generally cylindrically shaped opening 3 formed at its forward end for receiving a gun barrel 4. Suitable bearing means 5 are provided in cylindrical opening 3 for supporting barrel 4 and allowing only axial movement thereof relative to the housing. A barrel extension 6 forming a breech is rigidly connected to the inner end 7 of barrel 4 so as to represent an integral part thereof. As best shown in FIGURE 3 barrel extension 6 is supported within housing 2 by projections 8 formed on the inner wall of the housing so that it may move freely with the barrel.

A breechblock 9 slidably carried by barrel extension 6 provides the means for loading, firing and unloading the gun in response to axial recoil movement of the barrel. Breechblock 9 includes a base member or bolt slide 25 and a movable member or bolt block 26 slideably carried by the base member. A pair of door-like locking members or cam means 27 and 28 are swingably carried by movable member 26 through pins 29 and 30. Pins 31 and 32 provided on members 27 and 28 engage cam-like slots 33 and 34 formed on base member 25. The shape of slots 33 and 34 and such that when movable member 26 is moved rearwardly relative to the base member, the door-like locking members 27 and 28 are caused to move outwardly and engage notches 35 and 36 formed in barrel extension 6 and thereby lock the breechblock relative to the barrel extension. Thus, locking members 27 and 28 are similar to latches, and notches 35 and 36 are similar to keepers. An accelerator rod 18, generally co-axially aligned with barrel 4, is fixedly secured to base member 25 of breechblock 9 by means of pin 19. The forward end of rod 18 is formed as a firing pin 37 which is adapted to project through an opening 38 in movable member 26. The forward end of movable member 26 is formed with a T-slot 39 for supportingly engaging the head of an ammunition round as best shown in FIGURE 2. The length of rod 18 is such that firing pin 37 at the forward end thereof engages the head of bullet 40 and thereby causes it to fire when movable member 26 is moved rearwardly relative to base member 25 for locking the breechblock. This action occurs by pushing the base member 25 forwardly after the movable member 26 butts against the forward end of barrel extension 6.

A fluid-filled hydraulic cylinder 10 formed rigid with housing 2 is adapted to slidably receive a driving piston 11 adjacent its forward open end 12. In the opposite end of hydraulic cylinder 10 a shock absorbing buffer piston 13 is arranged to move axially of the housing against the action of a spring 14. As shown in FIGURE 1 the pressure exerted by spring 14 against buffer piston 13 may be varied by the adjusting plug 15.

A piston chamber 16 formed as a part of housing 2 and generally co-axially aligned with barrel 4 is provided with an opening 17 at its forward end for receiving accelerator rod 18. A driven piston 20 slidably carried within chamber 16 is provided with an axial bore arranged to slidably receive the rearward end 21 of rod 18 extending within the chamber. A head 22 formed on the extreme rearward end 21 of rod 18 projecting beyond piston 20 butts thereagainst to limit the relative movement between the piston and the rod so that as piston 20 is caused to move rearwardly the breechblock is caused to move with it. A port 23 connects cylinder 10 with chamber 16 so that fluid within chamber 10, when pressurized through the action of driving piston 11, will exert a force on driven piston 20 in chamber 16. A radial cut-out 24 in the outer periphery of the driven piston at the forward end thereof allows the fluid pressure to exert a force urging the piston rearwardly within chamber 16 even when the piston is in the extreme forward position butting against the forward wall of chamber 16.

A breechblock buffer cylinder 41 is arranged rearwardly of chamber 16 and forms a part of housing 2. A buffer piston 42, slidably received within cylinder 41, is urged in an extreme forward position, a shown in FIGURES 1 and 2, by means of a spring 43 acting between piston 42 and an adjusting plug 44. An aperture 45 formed in piston 42 and in the rearwa d end of chamber 16 permits rod 18 carried by the breechblock to extend into buffer cylinder 41 as required to allow the necessary movement of the breechblock for the loading and unloading operations of the gun. A breechblock return spring 46 acting between piston 42 and base member 25 of the breechblock urges the latter into the forwardmost locked position shown in FIGURES 1 and 2. A guide pin 47 secured to piston 42 and extending into an opening 48 formed in breechblock 9 provides a suitable guide for spring 46.

A normally projecting extension 49 on barrel extension 6 carries a hammer 50 threadedly engaging extension 49 and co-axially aligned with opening 12 in the forward end of chamber 10. Thus as barrel 4 is moved rearwardly hammer 50 is caused to engage driving piston 11 in chamber 10 and compress the fluid stored therein whereby to exert a force on driven piston 20 for causing it to unlock and accelerate breechblock 9 rearwardly relative to the barrel and barrel extension. Hammer 50 is spaced a predetermined distance from piston 11 to permit barrel 4 and breechblock 9 to move rearwardly together a short distance while the gasses within the barrel produced by firing a round of ammunition are allowed to subside so as to avoid "blowback" and to permit unlocking of the breechblock. By varying the distance of hammer 50 from piston 11, the firing rate of the gun may be varied since this adjustment controls the amount of energy which will be imparted to driving piston 11.

Additional control over the firing rate of the gun may be provided as shown in FIGURE 1 wherein piston 51

to effect first disengagement of said locking member from said notch means and then movement of said movable member from its operative position to its inoperative position while said barrel is recoiling.

5. In an automatic machine gun having a housing, a longitudinally movable barrel carried by said housing and a movable member carried within said housing for guided movement from a firing position adjacent said barrel to a loading position spaced from said barrel, releasable locking means on said movable member engageable with said barrel for releasably locking said movable member to said barrel when said movable member is at firing position, a base member engaged with said locking means and said movable member and movable from one terminal position where it causes said locking means to retain said movable member at firing position to another terminal position where it retains said movable member at loading position, and a hydraulic accelerator comprising, a fluid-filled chamber rigidly carried by said housing, a piston slideably carried within said chamber adjacent one end thereof for pressurizing the fluid upon actuation, piston actuating means rigidly carried by said barrel for actuating said piston and pressurizing the fluid within said chamber in response to rearward recoil movement of said barrel, and actuating means connecting with said base member and responsive to the pressure generated in said fluid during said rearward recoil movement for forcefully moving said base member from said one terminal position to the other terminal position while said barrel is recoiling for first causing the release of said locking means and then movement of said movable member from firing position toward loading position while said barrel is recoiling.

6. In a machine gun having a housing, a longitudinally movable barrel carried by said housing and a breechblock carried within said housing for guided movement from a firing position adjacent said barrel to a loading position spaced from said barrel, a first hydraulic cylinder containing fluid, a driving piston slideably mounted in said first cylinder adjacent one end thereof for pressurizing said fluid upon displacement toward the other end of said first cylinder, a second hydraulic cylinder connected to said first hydraulic cylinder, a driven piston slideably mounted in second cylinder for displacement therein in response to pressurization of said fluid, means connecting said breechblock with said driven piston so that displacement of the latter causes said breechblock to be moved from firing to loading position, and hammer means rigidly carried by said barrel engageable with said driving piston during recoil movement of said barrel for displacing said driving piston toward said other end of said first cylinder and pressurizing said fluid whereby said driven piston is displaced and said breechblock is moved to loading position.

7. In the machine gun of claim 6, a buffer piston in said first cylinder, and a compressible buffer spring, pressurization of said fluid when said driving piston is displaced by said hammer means acting on said buffer piston to displace the same and compress said buffer spring for absorbing shock loads applied to said driven piston and for pressurizing said fluid after recoil movement of the barrel is completed.

8. An automatic machine gun comprising: a housing, a gun barrel having an axial chamber in which a cartridge is adapted to be fired, said barrel being axially slideable on said housing for recoil movement from a forward in-battery position to a rearward recoil position; a barrel extension rigidly attached to said barrel adjacent the chamber; a base member having a firing pin thereon and mounted on said barrel extension so that said firing pin is coaxial with said chamber, said base member being axially slideable on said barrel extension for movement from a rearward recoil position remote from the chamber to a forward firing position adjacent the chamber where the firing pin is adapted to strike and fire a cartridge; a driving spring acting on said base member for urging the latter forwardly toward firing position; an accelerator on said housing engageable by said barrel extension during recoil movement of said barrel for moving said base member from firing position to recoil position against the action of said driving spring; a bolt block having an aperture therethrough and mounted on said barrel extension between said base member and said chamber so that said aperture is coaxial with said chamber, said firing pin being slideably mounted in said aperture and said bolt block being axially slideable on said barrel extension for movement from a rearward recoil position remote from the chamber to a forward firing position abutting the chamber; a locking member hinged to said bolt block for rotation from an inward position substantially parallel to said axis to an outward position inclined relative to said axis; and a pin on one member engaged in a slot in the other member to define a pin-and-slot connection means that connects said base member to said locking member; said connection means causing said locking member to rotate to its outward position when said base member moves forwardly relative to said bolt block sufficiently to project said firing pin forwardly of said bolt block, said connection means causing said locking member to rotate to its inward position when said base member moves rearwardly away from said bolt block sufficiently to withdraw said firing pin into said bolt block, said connection means coupling said base member to said bolt block when said locking member is in its inward position for causing said bolt block to move with said base member when the latter moves rearwardly; said barrel extension having a side engageable with said locking member when said bolt block is between recoil and firing position for preventing said locking member from rotating to its outward position, said connection means coupling said bolt block to said base member when said locking member is prevented from rotating to its outward position by said side while said driving spring moves said base member forwardly toward firing position for causing said bolt block to move forwardly with said base member until said bolt block reaches firing position, said barrel extension having a notch which effects rotation of said locking member to its outward position when said bolt block is at firing position, movement by said driving spring of said base member to firing position when said bolt block is in firing position causing said connection means to rotate said locking member to its outward position and into said notch and said firing pin to slide forwardly in said aperture until it projects forwardly to said bolt block and fires a cartridge in said chamber, said locking member when in outward position in said notch preventing rearward movement of said bolt block toward its recoil position whereby said bolt block is attached to said barrel extension when a cartridge is fired, initial rearward movement of said base member by said accelerator from firing position toward recoil position causing said firing pin to slide rearwardly in said aperture until it is withdrawn into said bolt block and causing said connection means to rotate said locking member out of said notch to its inward position whereby said bolt block is detached from said barrel extension, further rearward movement of said base member by said accelerator to recoil position causing said connection means to couple said bolt block to said base member whereby said bolt block is moved rearwardly to recoil position by said base member.

References Cited in the file of this patent

UNITED STATES PATENTS

690,955	Horne	Jan. 14, 1902
1,351,141	Thompson	Aug. 31, 1920
1,906,800	Marek	May 2, 1933
1,987,939	Lahti	Jan. 15, 1935
2,453,830	Chadwick et al.	Nov. 16, 1948

FOREIGN PATENTS

812,040	Great Britain	Apr. 15, 1959

CHRONOLOGY OF THE HYDRAULIC ACCELERATOR MACHINE GUN

July 1951	-Presentation by AAI Corp. of the Hydraulic Accelerator concept to the U. S. Army
August 1951	-Proposal submitted to modify a standar caliber .50 M.G. to incorporate the Hydraulic Accelerator
November 1951	-Contract awarded
March 1952	-Contract amended to start preliminary design of a new M.G. (T175) with Hydraulic Accelerator
July 1952	-Tests begin with modified Cal. 50 M.G.
March 1953	-Tests completed. Hydraulic Accelerator concept accepted.
May 1953	-Contract amended to allow design, development, test of a Hydraulic Accelerator, independent of any particular gun.
August 1953	-T175 preliminary design complete. Detail design initiated.
September 1953	-Tests of Accelerator initiated using pendulum test stand.
December 1953	-T175 detail fabrication completed.
January 1954	-T175 functional testing initiated using pendulum test stand.
March 1954	-Second contract for two T175 pre-production prototypes awarded.
April 1954	-Hydraulic Accelerator tests complete.
June 1954	-First firing tests of T175. Test report on Hydraulic Accelerator submitted.
December 1954	-Several 10 round burst successfully fired.
January 1955	-Completion of first contract, final report submitted. Total contract value $152,000.

EXHIBIT C-4

March 1959 -Completion of second contract, final report submitted. Total contract value $486,000. Gun incorporated a mechanical accelerator and was designated T175E1. Gun is now designated the M85 and is being produced for the Army by General Electric.

December 1959-Patent application filed by I. R. Barr.

October 1962 -Patent granted (No. 3,058,398)

EXHIBIT C-4